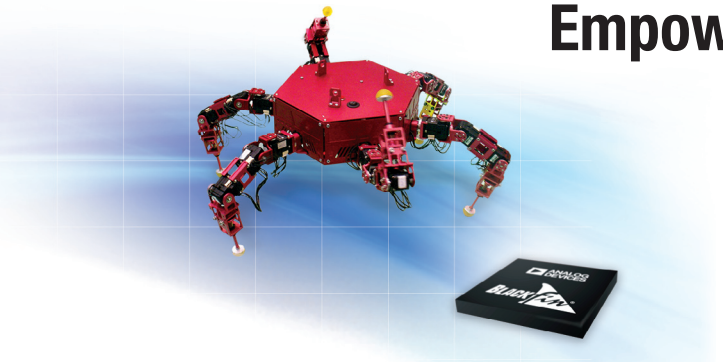
Graphical Embedded System Design Empowers Life Saving Spider Robots



By Pom Yuan Lam (BEng), Lecturer, Nanyang Polytechnic, Singapore

A six legged robotic spider was designed for operation in tough, rugged environments with highest degrees of freedom for best mobility. Low development risk, highest functionality, and smart embedded software were joined with a new and unique design methodology, combining graphical programming with high computing processing performance and an ultralow energy scheme. The key technologies include the Blackfin® processor, the NI LabVIEW® Embedded Module for Blackfin Processors, and the ZMobile® mixed-signal platform.

Designed for Missions in Rugged Environments

The primary purpose of any life saving equipment is to protect against additional loss of human life, while locating any casualties as quickly as possible. With this is in mind, the development of the six legged robotic spider to support rescue operations during catastrophe missions, such as, collapsed buildings after an earthquake (see Figure 1), was completed to empower a complete robotic solution. Thanks to its mobility, small size, and on-board intelligence, the spider can avoid various obstacles and enter difficult-to-reach locations to search for trapped victims. Replacing humans in dangerous missions (for example, sweeping and neutralizing minefields) is another potential application area. These challenges are met by a highly mobile walking scheme.

Figure 1. With "creeping" as one of many motion patterns, the robot spider can squeeze through tight spaces.

Six independent legs allow the robot to move in an omnidirectional fashion, even on terrain where robotic movement normally is not possible or too risky. "Walking" and "rotating" belong to the basic high level motion patterns and have been adopted from six legged insects. Three moving and three lifted "feet" enable the desired walking speed, providing a sufficient equilibrium that is required for harsh terrain. "Creeping" is a special motion allowing the robot to squeeze through tight spaces and narrow slots (see Figure 1).

Multifunctional Mechatronic System

The leg mechanics and motion control are the key features of the spider robot. A total of 24 smart dc brush motors not only drive the legs but also function as integral joints of the walking mechanics. This leads to a sturdy yet light weight construction, reducing power consumption and improving motion dynamics.

Besides its legs, the hexapod robot features typical autonomous robotic subsystems, including machine vision, distance measurement, and wireless communication. The embedded hardware and two 7.2 V lithium polymer batteries, including the fuel gauges, reside in the robot's rigid body. Mission parameters, I/O settings, and new motion gaits can be transferred wirelessly or through removable media (see Figure 2 and Figure 3).

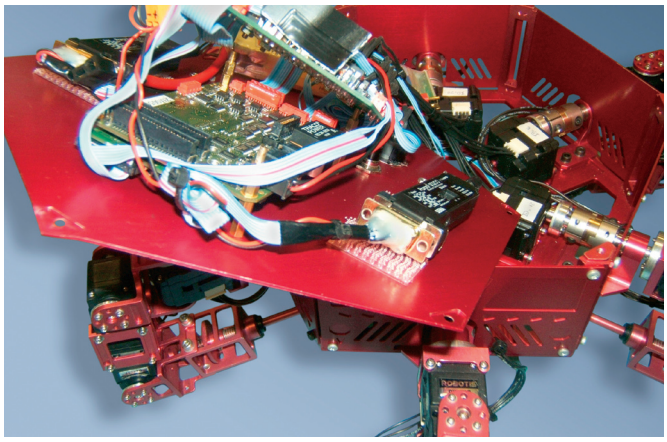


Figure 2. Under the hood, the hexapod robot features machine vision, distance measurement, and wireless communication. It is powered by two lithium polymer batteries.

Smart Motion with 24 Degrees of Freedom (24DOF)

The spider's low level movements rely on complex mathematical models calculated at runtime. Thanks to the enormous embedded computing power of the Analog Devices Blackfin processor and Schmid Engineering's deterministic real-time services, the motion looks determined, dynamic, and smooth. High level LabVIEW VIs (vertical instruments), as well as hand-optimized Blackfin math libraries, are used for the continuously running inverse kinematics algorithm. This algorithm, including trigonometric functions and matrix operations, finds suitable joint angles, Θ_1 and Θ_2, to exactly move the end effector along a desired trajectory in a space (X, Y, Z) (see Figure 4). Depending on the high level motion pattern, the trajectory vectors move along calculated lines, rectangles, or circles.

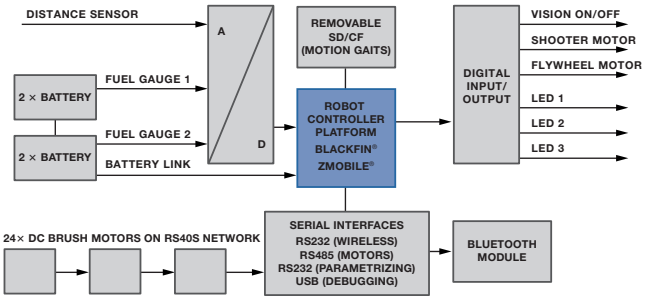


Figure 3. The ZMobile platform integrates and links to the whole process I/O and provides high level functions blocks.

The trajectories can be programmed in three different ways:

- Teach-in and playback as a common technique for design and training new or special patterns.
- 3D CAD software allows for visually checking the simulated trajectories. The models are exported as virtual reality files and imported in LabVIEW's picture controls. Movements are now tuned by comparing the virtual with the real model.
- Continuously calculated trajectories at runtime by the inverse kinematic algorithm.

This is done in parallel for all joint angles of all six legs, resulting in 24 continuously calculated setpoints for all motors to ensure dynamic motion. These setpoints are transferred to each motor via a serial RS-485 network and turned into physical actions by decentral PD controllers (see Figure 5). Position feedback and temperature readings of all 24 actuators are acquired over the very same network. The famous limbo dance the two robots performed simultaneously at the Singapore robot competition (Figure 6) demonstrated the outstanding movement capabilities.

Smart Vision and Distance Sensing

Beyond the smart motion and freedom of movement, an intelligent camera and a distance measurement sensor are featured in the "eye" of the spider robot. Objects and substances are localized and tracked by high performance image processing algorithms such as finding a centroid within a region of interest. The "eye" can also be programmed to identify any color within its vicinity. Future versions will include improved image processing, pattern matching, and edge detection: leveraging the Blackfin processor's computational power and high speed image acquisition to take smart vision to the next level.

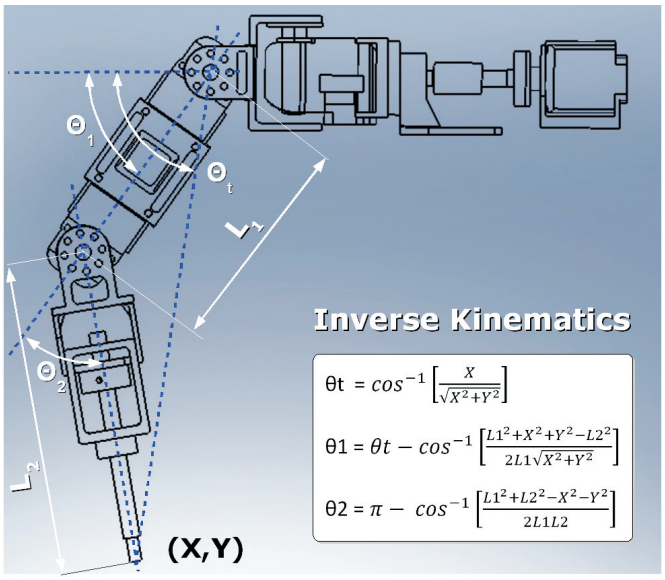


Figure 4. Smooth motion is achieved by inverse kinematics relying on trigonometric functions and matrix operations.

Wireless Communication with Bluetooth

Providing the ability to communicate on any level with the robot, a permanent wireless Bluetooth communication interface is maintained with the "outer world":

- Debugging channels for the ZMobile Fast Debug Mode during development and test.
- Reading critical parameters such as motor status and battery level for system diagnostics.
- Online acquisition of vital algorithm variables for tuning.
- Downloading new mission data prior to an operation.

During the robotics competition, two robot spiders were linked through the wireless communication channel to synchronize their movements (see Figure 6). This was the prototype for a more serious scenario where several robot spiders are given a task to complete as a team.

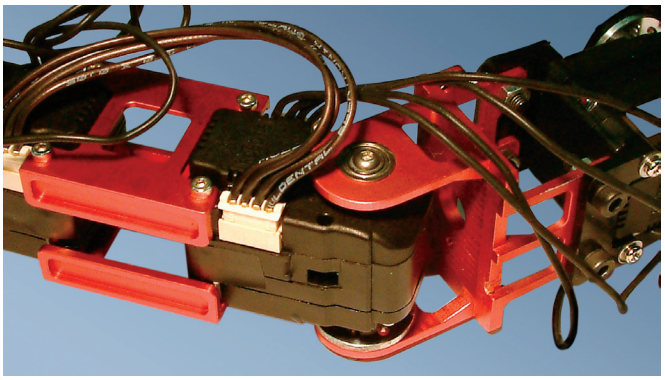


Figure 5. The four smart motors with built-in programmable PD controllers and addressed by a serial RS-485 network are seamlessly integrated in the limbs.

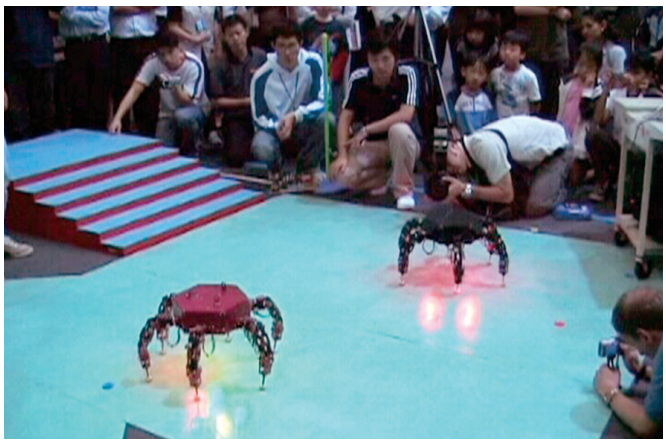


Figure 6. The robotic duo "Wincy" and "Incy" won the open category competition of the Singapore robotic competition held in January 2008. Both robots were synchronized through wireless communication.

ZMobile Low Power Embedded Hardware

The ultralow power mixed-signal ZMobile module is the "heart" of the spider robot. This module, powered by a Blackfin processor and LabVIEW Embedded, is supplied by the Swiss solution provider Schmid Engineering. Integrates sensors, actuators, vision, batteries, and wireless communication on a single platform. Nanyang Polytechnic chose the ZMobile platform for three reasons:

First, programming the spider in LabVIEW allowed the robot designers to concentrate on the primary functions of this cutting edge project right from day one. Thanks to the high productivity of graphical programming, the system engineers were able to add more functionality than originally specified during the same development period.

Second, an ultralow energy scheme, such as ZMobile dynamic power management, was a vital feature for this autonomous robot since operation time can now be significantly prolonged. The same applies to the ZMobile module's power consumption, which is in the milliwatt range, allowing most of the remaining energy that is stored in the on-board batteries to be used by the motors.

Third, the scalable process I/O slot gives room for integrating more sensors and actuators in the future.

Real-Time Graphical Embedded Software

The entire spider robot application software was programmed using the LabVIEW Embedded Module for Blackfin Processors 2.5, extended by the ZBrain BSP for NI LabVIEW from Schmid Engineering (see Figure 8). This provided the ideal embedded software platform providing high level programming, graphical debugging, graphical multitasking, and, at the same time, deterministic real-time behavior.

Object-oriented design patterns helped to further manage complexity on the graphical level. Main objects, such as motors or sensors, were abstracted by functional global variables, representing classes in LabVIEW.

The main application framework consists of several tasks:

- The top level main loop plans for actions and is represented by a classic state machine connecting to the other loops by software queues and synchronization means, such as semaphores.
- The communication task maintains a wireless data connection to the outside world.
- The vision task is responsible for the low level image processing and distance reading.
- The motion task manages high level motion patterns and low level limb control, and also monitors the motor's position and state.
- A housekeeping task acts as a common error handler. Events and errors are detected and logged to removable media along with timestamps for later retrieval. ZMobile features like watchdog, rebooting, and shutdown with programmed wake-up are efficient means to restart from scratch if error self-correction (for example, error rollback) don't succeed.

These loops run simultaneously as threads in a cooperative multitasking environment. Context switching in the millisecond range and microsecond real-time determinism on the driver level ensure smooth and glitch free movements. Finally, the heavy parallelism demands for thread safety of each software component and device driver were met by the maker's board support package.

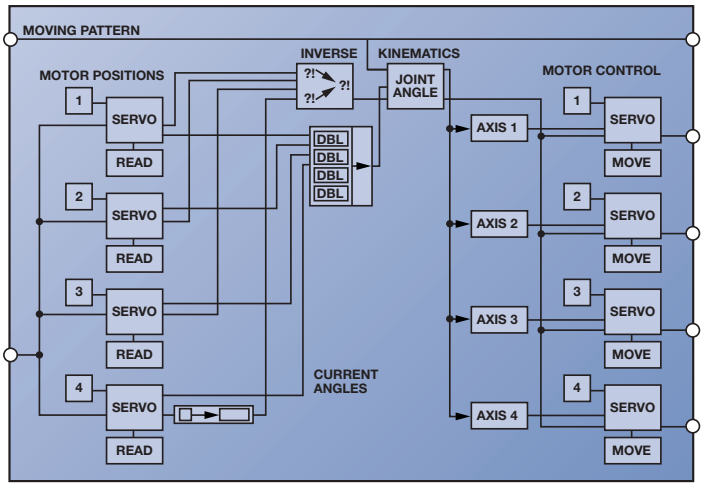


Figure 7. NI LabVIEW Embedded Module for Blackfin Processors generated real-time code, which was deployed on the low power Blackfin target ZMobile module.

Conclusion

The project of building a powerful and superior robot has been successful and development time was greatly reduced thanks to a graphical programming model using LabVIEW Embedded Module for Blackfin Processors and the high processor performance of the Blackfin processor. Schmid Engineering's graphical Fast Debug Mode turned out to be another booster during algorithm engineering, shortening development time by a factor of five. Therefore, the ZMobile module can be regarded as a "killer product" for user-friendly embedded system engineering, not only for robot designers but for anyone building mechatronic systems.

Advancements in vision, a smarter power management and energy harvesting scheme, sensor fusion, fuzzy logic, and GPS data collection are promising components to be added to the common mechatronic platform. Further, it is planned to reuse the modular hardware and software system in other mobile, autonomous, bio-inspired robots, such as one modeled on snakes.

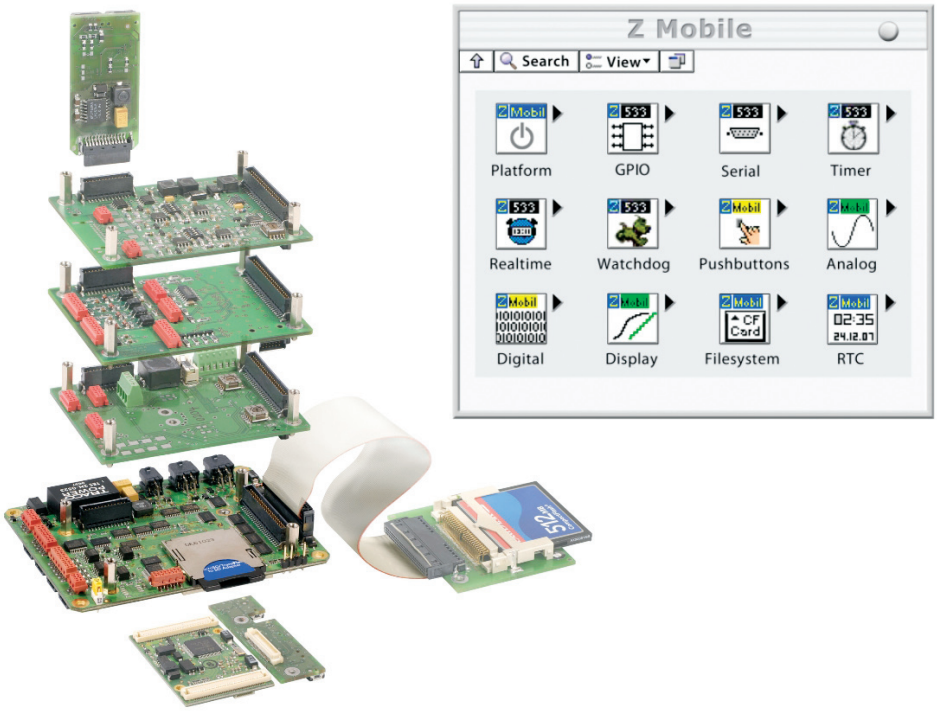


Figure 8. The entire robot is controlled by a ZMobile mixed-signal module powered by a Blackfin Processor and LabVIEW Embedded Module for Blackfin Processors.

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